

S. George Philander

El Niño

A Predictable Climate Fluctuation

El Niño is so versatile and ubiquitous — he causes torrential rains in Peru and Ecuador, droughts and fires in Indonesia, and abnormal weather globally — that the term is now part of everyone's vocabulary; it designates a mischievous gremlin. Hence, if the stock market in New York is erratic, or the traffic jams in London are exceptionally bad, it must be El Niño. This is consistent with our practice of using meteorological phenomena as metaphors in our daily speech: the president is under a cloud, the examination was a breeze. We know exactly what these statements mean because we have a life-long familiarity with clouds and breezes.

Despite all the publicity it receives, El Niño, Spanish for "Child Jesus," remains a puzzle. Why is the rascal named after Child Jesus? How can scientists claim that they are able to predict it months in advance when they are unable to predict the weather more than a few days ahead?

WHY "CHILD JESUS"?

Originally El Niño was the apposite name given to the warm, southward, seasonal current that appears along the barren coasts of Peru and Ecuador around Christmas when it provides a respite from the very cold, northward current that otherwise prevails. Every few years the southward current is exceptionally warm and intense, penetrates far south, and bears gifts. A visitor to Peru described one such occasion, in the year 1891, as follows: "... the sea

is full of wonders, the land even more so. First of all the desert becomes a garden. . . . The soil is soaked by heavy downpour, and within a few weeks the whole country is covered by abundant pasture. The natural seems impossible." The "wonders" in the sea can include long yellow and black water snakes, alligators, bananas, and coconuts (Philander S. G. H. *Is the Temperature Rising? The Uncertain Science of Global Warming*. Princeton University Press, 1998).

With time, we reserved the use of the term El Niño, not for the annual, coastal current, but for the more spectacular, interannual occurrences that affect much of the globe. Not only our terminology, but also our perceptions changed; we now have a pejorative view of El Niño, not because its character has changed, but because we have changed. Heavy rains still trans-

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form the desert into a garden, but they also wash away homes, bridges, and roads, products of economic development and of a huge increase in population. As our economy and numbers continue to grow, the damage inflicted by natural phenomena such as El Niño, hurricanes, and severe storms is likely to continue increasing, even in the absence of global climate changes.

HOW IS EL NIÑO RELATED TO THE SOUTHERN OSCILLATION?

Towards the end of the nineteenth century, scientists discovered that when atmospheric pressure is high over the western tropical Pacific, it is low over the eastern tropical Pacific and vice versa (Walker G.T. and E. W. Bliss. "World Weather V" *Mem Royal Meteorol. Soc.* 4, 53-84. 1932). This see-saw in pressure, known as the Southern Oscillation, has a period of approximately four years, and is associated with fluctuations in a number of other variables. For example, during one phase of the Southern Oscillation the trade winds are intense, and rainfall is heavy over the western Pacific but light over the eastern Pacific. During the complementary phase, the trades are weak, while rainfall is light over the western and heavy over the eastern tropical Pacific.

The reason for this interannual climate fluctuation became apparent in 1957 when, for the first time during the occurrence of El Niño, sea-surface temperatures across the entire Pacific were available. Those measurements revealed that the warming along the shores of Peru associated with El Niño is not confined to a narrow coastal zone but extends thousands of kilometers offshore and influences an area so enormous that the global atmospheric circulation is affected. This led Bjerknes (Bjerknes, J.

"Atmospheric Teleconnections from the Equatorial Pacific." *Mon. Weather Rev.* 97, 163-172. 1969) to realize that El Niño is one phase of the Southern Oscillation, as is evident in Figure 1. El Niño is a period of high sea-surface temperatures and heavy rainfall in the eastern Pacific, of droughts in the "maritime" continent of south-eastern Asia and northern Australia. During El Niño of 1997-98, the droughts in the west contributed to devastating forest fires, while in the east, tropical storms spawned off Mexico, and heavy downpours drenched Chile and Peru. Usually El Niño is followed by its complement, known as La Niña, a period of low sea-surface temperatures and dry conditions in the eastern tropical Pacific, and plentiful rainfall in the western tropical Pacific. Figure 2 (see page 13) depicts El Niño and La Niña which, together, constitute the Southern Oscillation.

THE CIRCULAR ARGUMENT THAT EXPLAINS THE SOUTHERN OSCILLATION

The changes in the temperature patterns of the tropical Pacific Ocean shown in Figure 2 induce the Southern Oscillation. Of particular importance are changes in the regions of maximum surface temperature. The air often rises spontaneously over such regions, creating tall cumulus towers that provide plentiful rainfall locally. To sustain the rising

motion, winds in the lower atmosphere converge onto the regions of maximum temperature. Those winds, the trades over the Pacific, harvest moisture over the oceans and deposit it in the cumulus clouds. During La Niña, the warm

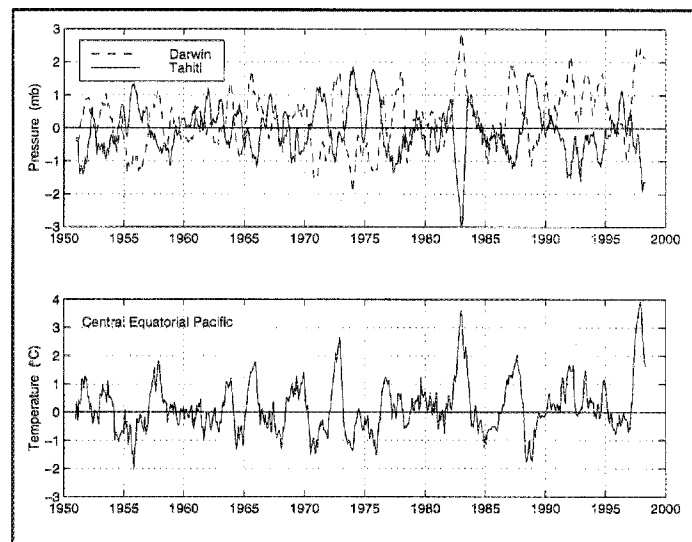


Figure 1: The Southern Oscillation, the interannual fluctuations in pressure that are out of phase at Darwin (Australia) and Tahiti. These variations are highly coherent with those in sea-surface temperature in the central equatorial Pacific. The lower panel shows the departure of sea-surface temperature from 22°C.

waters of the tropical Pacific (under the region of heavy rainfall) are confined to the west. During El Niño, the eastern equatorial Pacific becomes warm, and the region of cumulus towers and heavy rainfall shifts eastward. This explanation for the climate fluctuations associated with the Southern Oscillation leads to another question: What causes the sea-surface temperatures to change?

Temperature patterns at the surface of the ocean reflect subsurface oceanic conditions. The ocean is effectively composed of two layers of fluid: a shallow surface layer of warm water, some 100 meters deep, above a deep, cold layer that extends to depths in excess of 4 km. The thermocline, a thin region of large vertical temperature gradients, separates the two layers. In the absence of any winds, the thermocline, which is the interface

between the warm and cold water, is horizontal. Under such conditions, the warm surface waters are spread uniformly over the cold layer. There is a tendency toward this state during El Niño when the trades are weak. The intensification of those winds, during La Niña, drives the warm surface waters westward, causing the thermocline to tilt down-

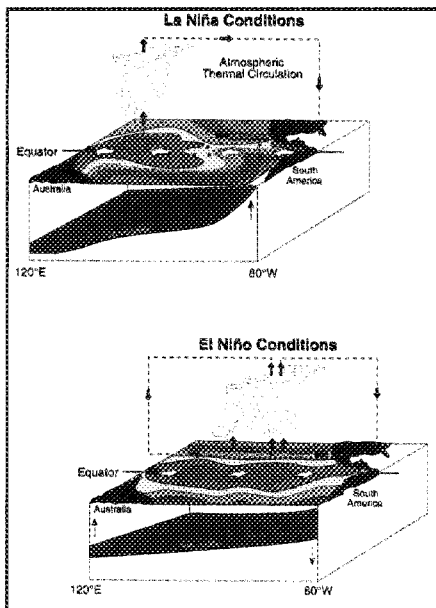


Figure 2: A schematic view of La Niña (top) and El Niño (bottom). During La Niña, intense trade winds cause the thermocline to have a pronounced slope from east to west so that the equatorial Pacific is cold in the east, warm in the west where moist air rises in cumulus towers. The air subsides in the east, a region with little rainfall except in the doldrums where the southeast and northeast trades converge. During El Niño the trades along the equator relax, as does the slope of the thermocline when the warm surface waters flow eastward.

ward to the west so that the cold water becomes exposed to the surface in the east. (See Figure 2.) Hence, from an oceanographic perspective, the Southern Oscillation corresponds to a sloshing, back and forth across the Pacific Ocean, of the warm surface waters in response to trade winds that fluctuate from weak (during El Niño) to strong (during La Niña).

From an atmospheric perspective, changes in sea-surface temperatures cause the Southern Oscillation, including changes in the winds over the Pacific. From an oceanic perspective, those changes in the winds cause the sea surface temperature changes. In response to this circular argument, it is tempting to ask which changed first, the winds or the temperatures? This is a futile approach, equivalent to asking whether the chicken or the egg came first. It is far more rewarding to explore the behavior of the coupled ocean-atmosphere system. Consider a random disturbance which, at the height of La Niña, causes a slight relaxation of the trades. Those winds drive the warm surface waters westward and cause the region of high temperatures, rising air, and heavy rainfall to be confined to the western Pacific. A weakening of those winds therefore causes some of the warm water to start flowing back eastward, thus expanding the region of high surface temperatures. The difference in temperature between the eastern and the western Pacific, which drives the winds, is now smaller, so that the winds become weaker. In other words, the change in ocean temperatures reinforces the initial weakening of the wind.

As a result, even more warm water flows eastward, causing a further weakening of the winds. An initial, cautious retreat by the trades induces a tentative eastward step by the warm surface waters, which hastens the retreat, which in turn emboldens the pursuit. The interactions between the ocean and atmosphere amount to an escalating tit-for-tat (a positive feedback) that causes the warm surface waters and humid air to surge across the tropical Pacific. Soon they are hugging the shores of Latin America, and El Niño has arrived. Once El Niño is established, the stage is set for La Niña to make its entrance. This new phase of the Southern

Oscillation is an inversion, a mirror image, of the first part of this tango for ocean and atmosphere. A slight intensification of the winds drives some of the warm water westward, thus increasing the temperature difference between the eastern and the western Pacific. That increase makes the winds stronger, which causes the temperature difference to become even bigger, and so on until La Niña is established.

El Niño and La Niña are beautiful examples of how the whole can be greater than the sum of the parts. The ocean, by itself, cannot produce the Southern Oscillation unless the winds over the ocean fluctuate in a certain manner. The atmosphere by itself is also incapable of producing the Southern Oscillation unless the sea surface temperatures vary in a certain manner. Together, the ocean and the atmosphere can interact and spontaneously produce a Southern Oscillation with wind and temperature fluctuations that are perfectly orchestrated. To ask why El Niño or La Niña occurs is equivalent to asking why a bell rings or a taut violin string vibrates. The Southern Oscillation is a natural mode of oscillation of the coupled ocean-atmosphere system; it is the music of the atmosphere and the hydrosphere.

The atmosphere and the ocean are partners in a dance. But who leads? Which one initiates the eastward surge of warm water that ends La Niña and starts El Niño? Though intimately coupled, the ocean and the atmosphere do not form a perfectly symmetrical pair. Whereas the atmosphere is quick and agile and responds nimbly to hints from the ocean, the ocean is ponderous and cumbersome and takes a long time to adjust to a change in the winds. The atmosphere responds to altered sea surface temperature patterns within a matter of days or weeks; the ocean has far more inertia and takes months to reach a new equilibrium.

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The state of the ocean at any time is not simply determined by the winds at that time because the ocean is still adjusting to and has a memory of earlier winds, a memory in the form of waves below the ocean surface. They propagate along the thermocline, the interface that separates warm surface waters from the cold water at depth, elevating it in some places, deepening it in others. These vertical displacements of the thermocline effect the transition from one phase of the Southern Oscillation to the next so that it is of critical importance to monitor oceanic conditions in order to anticipate future developments. That is why oceanographers developed and now maintain the measurement array shown in Figure 3. On the basis of such oceanic measurements, which were available on the World Wide Web a few days after the measurements had been made, scientists were able to anticipate the arrival of the El Niño of 1997–98 months in advance and could alert the public to the impending changes in weather and climate.

THE PREDICTABILITY OF EL NIÑO

A bell, to ring, must be struck, after which its oscillations last for a while before dying out. It appears that there are periods during which the Southern Oscillation “rings” by itself, and periods when a disturbance (blow) is needed to start it “ringing” again. During the 1980s it seemed to be ringing — El Niño of 1982 and of 1987 were both followed by La Niña episodes, but El Niño of 1992 persisted for several years, as if a new disturbance were needed for the ocean-atmosphere system to start ringing again. Disturbances

that can excite El Niño very effectively, because their surface winds have a spatial structure that coincides with those of the Southern Oscillation, are two-week bursts of westerly winds that sporadically occur over the far western equatorial Pacific. Such wind bursts were influential in initiating El Niño of 1997–98. Will the ringing now continue, with another El Niño making its appearance in the year 2002?

Evidence that the Southern Oscillation is subject to long-term modulations, so that it is prominent and energetic during some decades, less so during others, is available from coral records that cover a century or more. One of the factors responsible for this modulation is the time-averaged depth of the equatorial thermocline, which depends on exchanges between the tropical and the extra-tropical oceans. Current research on the Southern Oscillation is

therefore concerned with ocean-atmosphere interactions, not only in the tropics, but also in higher latitudes.

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READ MORE ABOUT IT:

The Journal of Geophysical Research, vol. 103, C7, June 29, 1998, is devoted to a series of excellent review articles concerning El Niño and related topics.

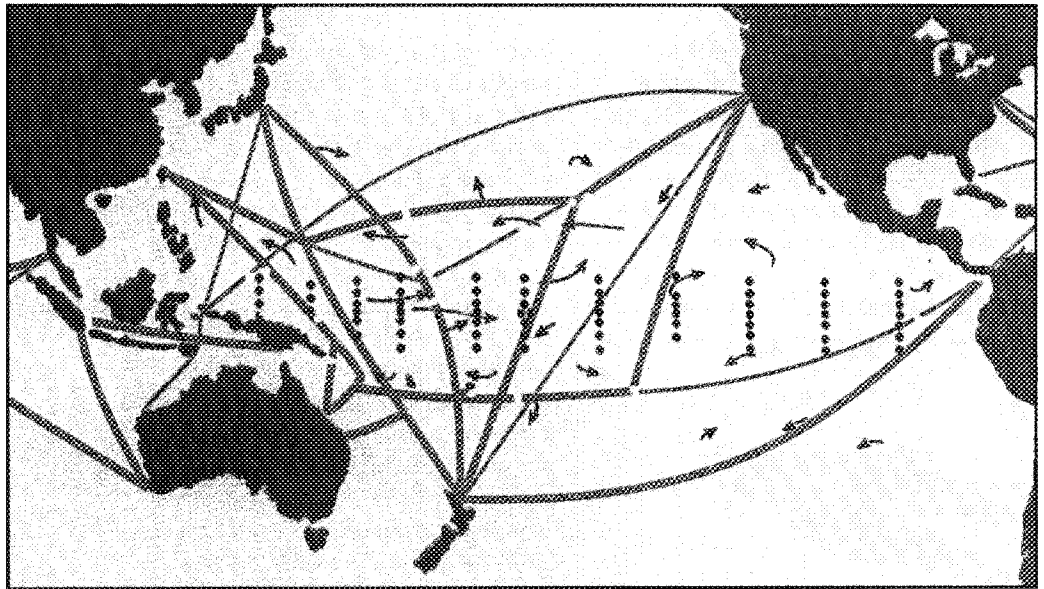


Figure 3: The array of instruments that monitor oceanic conditions. All these measurements are relayed to stations on land, in “real time.” The web site (<http://www.pmel.noaa.gov/togatao/ftp.html>) displays some of the measurements. The blue lines show the tracks of commercial ships that deploy instruments which measure temperature to a depth of a few hundred meters. The arrows show drifting buoys which measure temperature and the winds, and whose movements yield information about surface currents. The yellow dots are tide gauges that measure sea level which depends on the average temperature of a water column. The red diamonds, representing buoys moored to the ocean floor, show locations where temperature is measured over the upper few hundred meters of the ocean. The red squares indicate where oceanic currents are measured.